The large scale HI distribution in the Milky Way disk and halo

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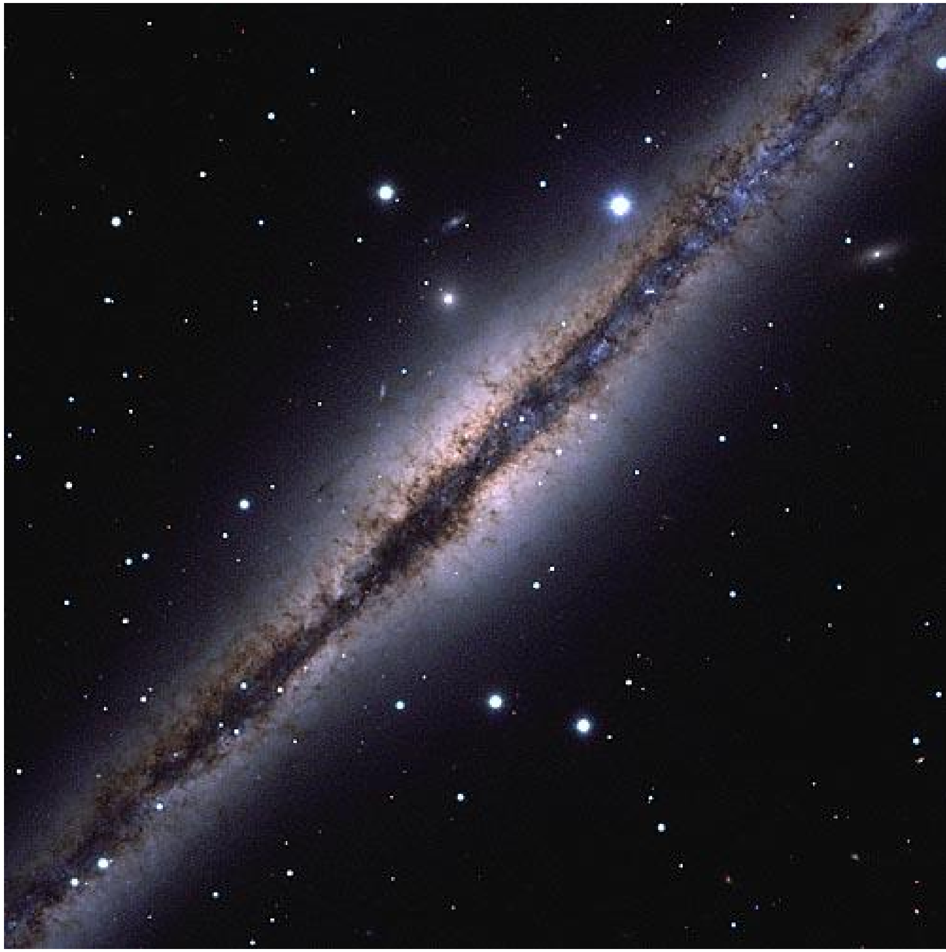
Rationale behind this talk:

- What means halo?
  - Outside the plane?
    - What defines the Galactic disk?
- Extra-planar = anomalous?
  - Normal gas belongs to the disk
    - rotates similar to the stars
    - is bound to the disk
    - has limited velocities
- We first need a definition of
  - the Galactic disk
  - the „normal“ gas
    - scale height
    - velocity dispersion
    - „phase space“



Use HI data from the LAB survey.....

- Derived density distribution depends on the **rotation curve**
  - depends on **mass distribution**
    - allows to **check Milky Way mass models**

- Model the mass distribution in a self-consistent way
  - **HI flaring** is most sensitive to the mass distribution

- Iterative solution of the Poisson and Boltzmann Eqs.
  - Bar, bulge, thin, thick stellar disk, gaseous disk, halo
  - Use all known observational constraints
  - check n(R,z,az) for R < 40 kpc, z < 15 kpc

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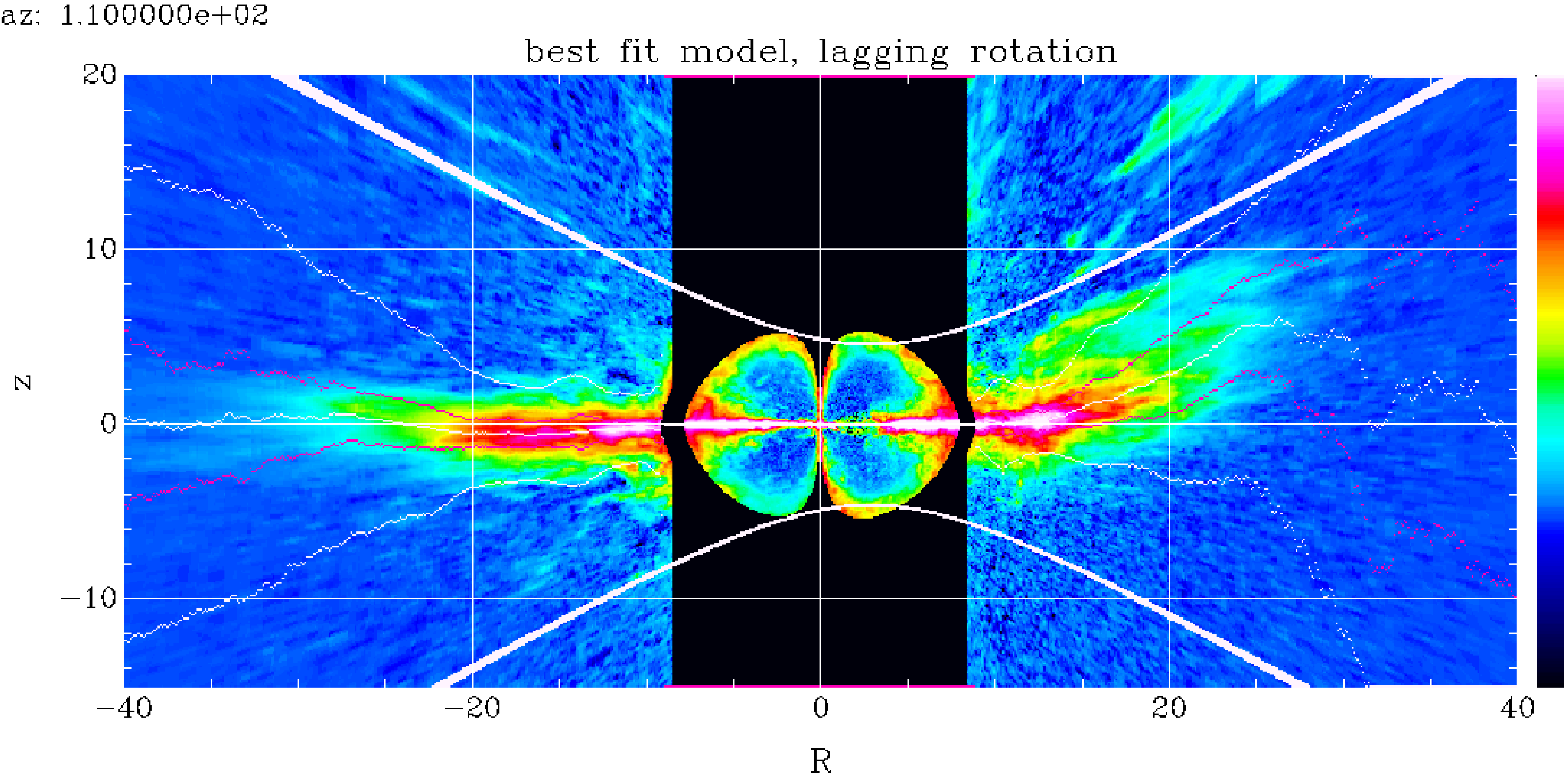
HI volume density at az = 110°



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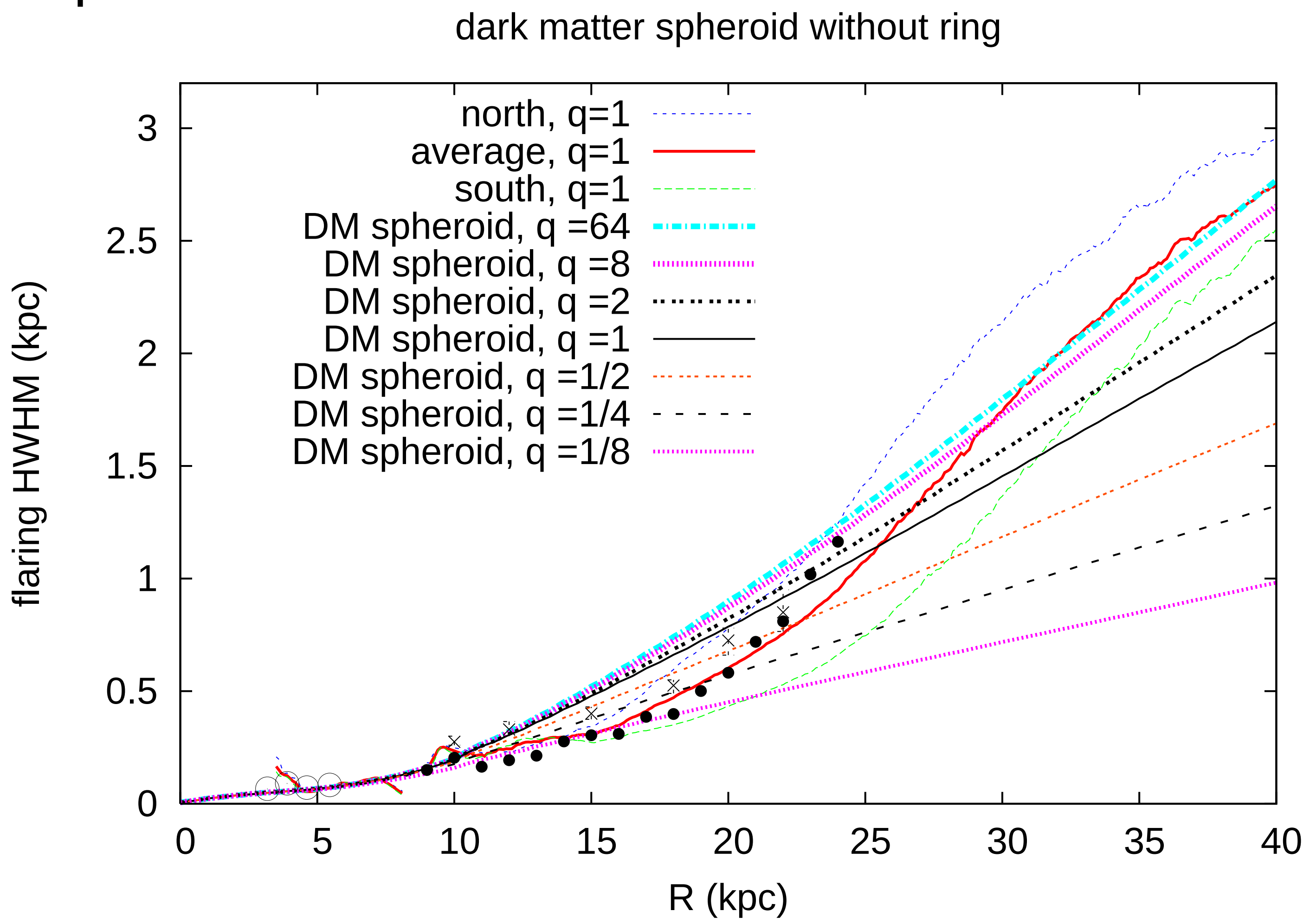
The mass model - conventional

- spheroidal halo



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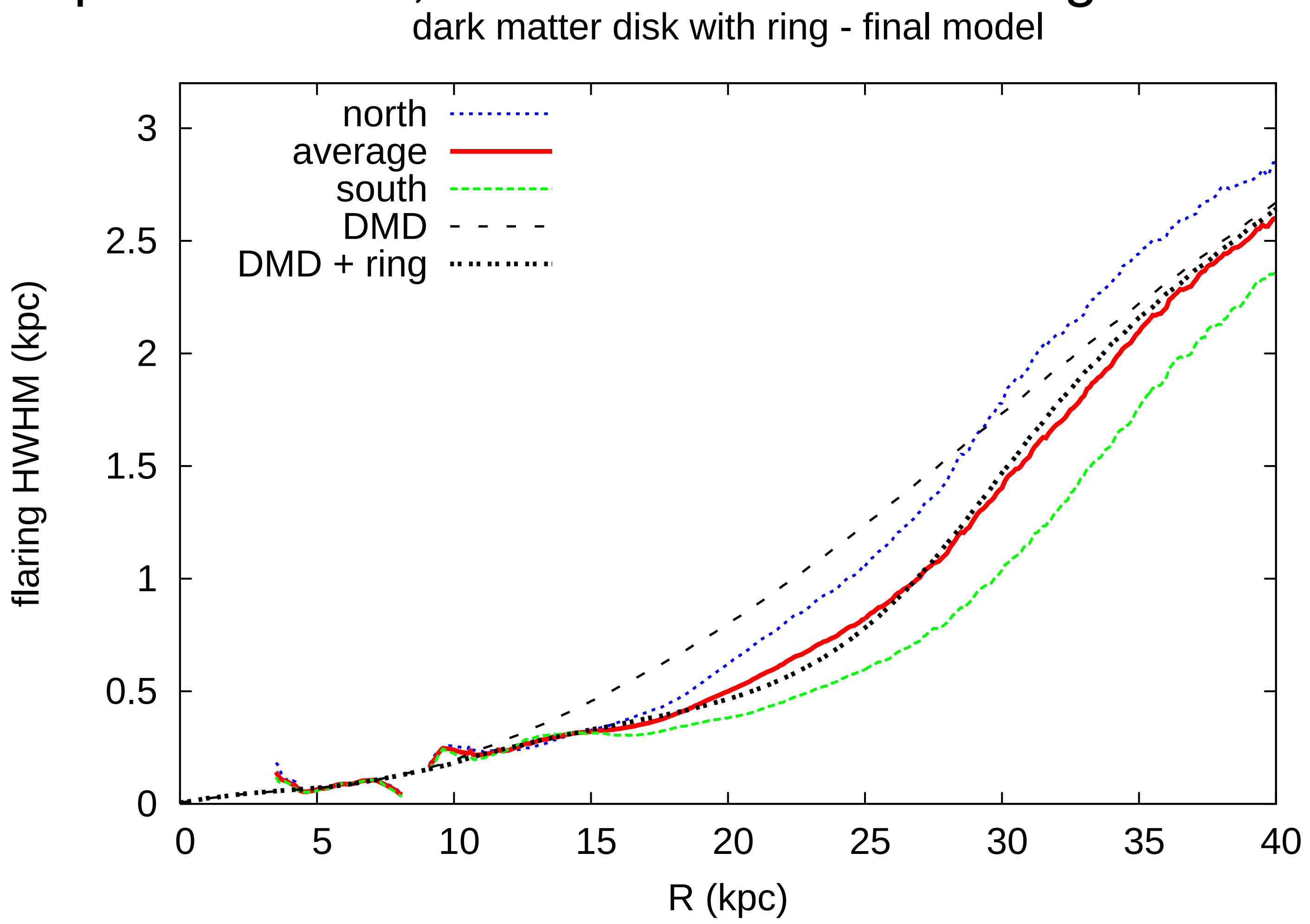
The mass model – best fit

- spherical halo, dark matter disk and ring



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Milky Way dark matter – best fit model

- An isothermal dark matter **halo** is needed to explain the mass distribution on large scales up to 350 kpc
  - Core radius 35 kpc, mass 1.8 10^{12} M_{sun}

- Within the Milky Way disk (<50 kpc) there is dark matter within a **thick exponential disk**
  - Mass: 1.8 10^{11} M_{sun}, twice the mass of all visible matter
  - radial exp. scale length 7.5 kpc, twice the scale length of the gas
  - scale height 10 times gaseous, velocity dispersion σ=105 kms^{-1}

- There is a significant mass concentration in a **ring**
  - Mass: 2 10^{10} M_{sun}
  - R = 13 – 18.5 kpc, extension 5 kpc in R, 1.7 kpc in z

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Mass model – properties (Kalberla et al., 2007)

- **dark matter ring mass** consistent with
  - EGRET excess γ-ray emission (de Boer et al., 2005)

- **dark matter ring position** coincident in with
  - stellar streams, but the stellar mass is only 2 10^8 - 10^9 Msun (e.g. Ibata et al., 2003)

  - **disk mass ratio (2/3 dark)** consistent with
  - collisional debris from dwarf Galaxies (NGC5291) (Bournaud et al. 2007)

- **HI distribution and spiral arm features** consistent with
  - Levine et al. (2006)

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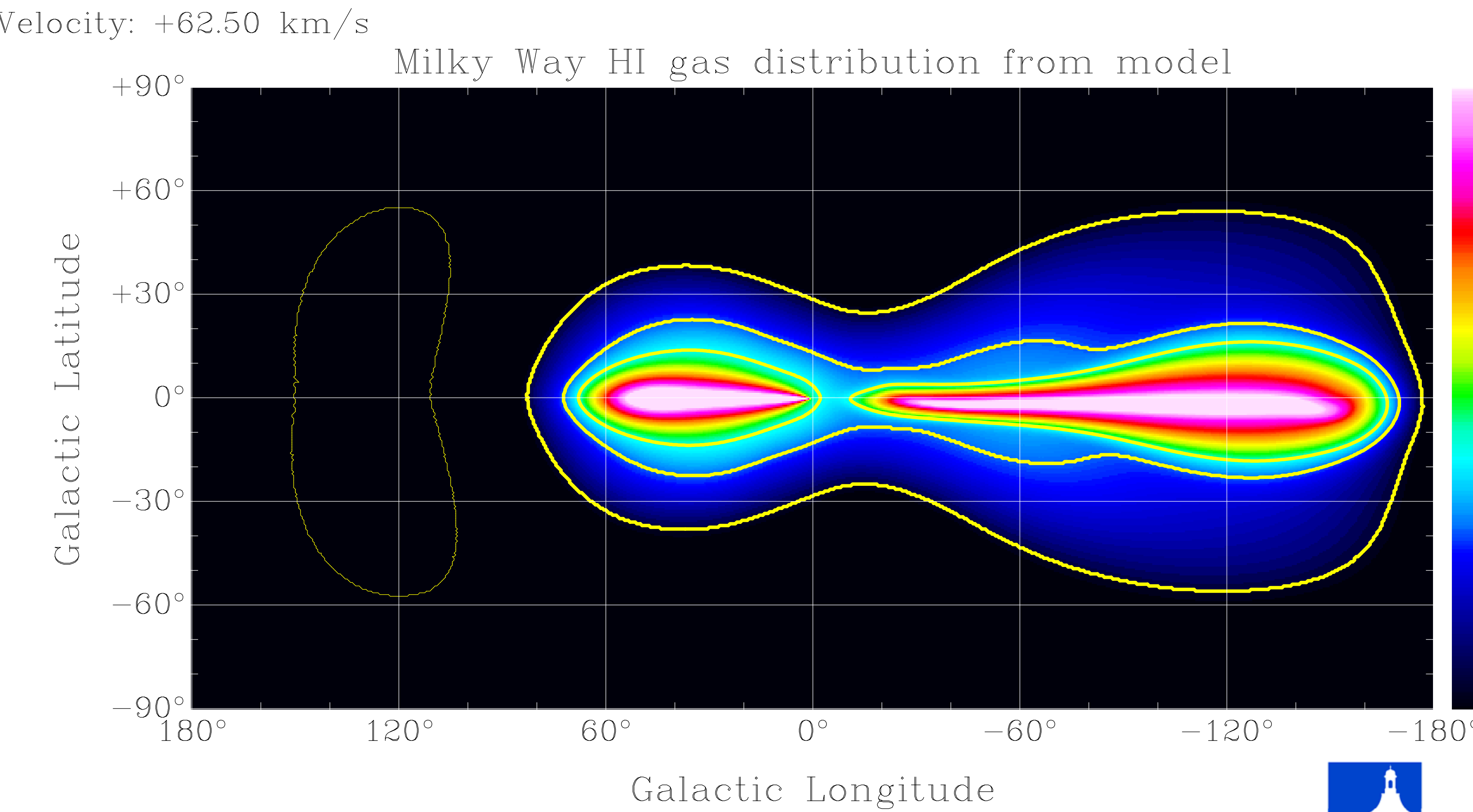
Consequences for the HI distribution



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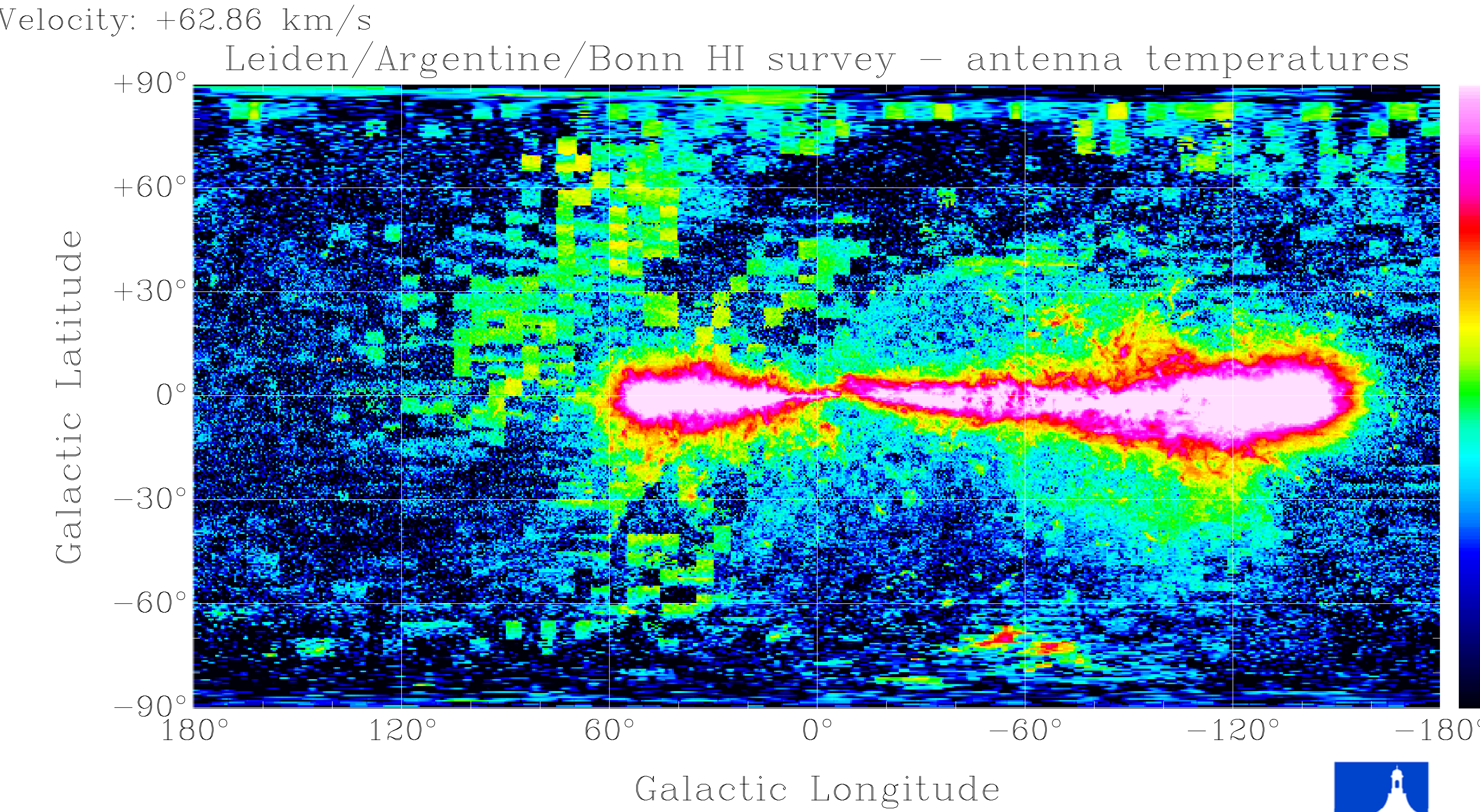
Observed...



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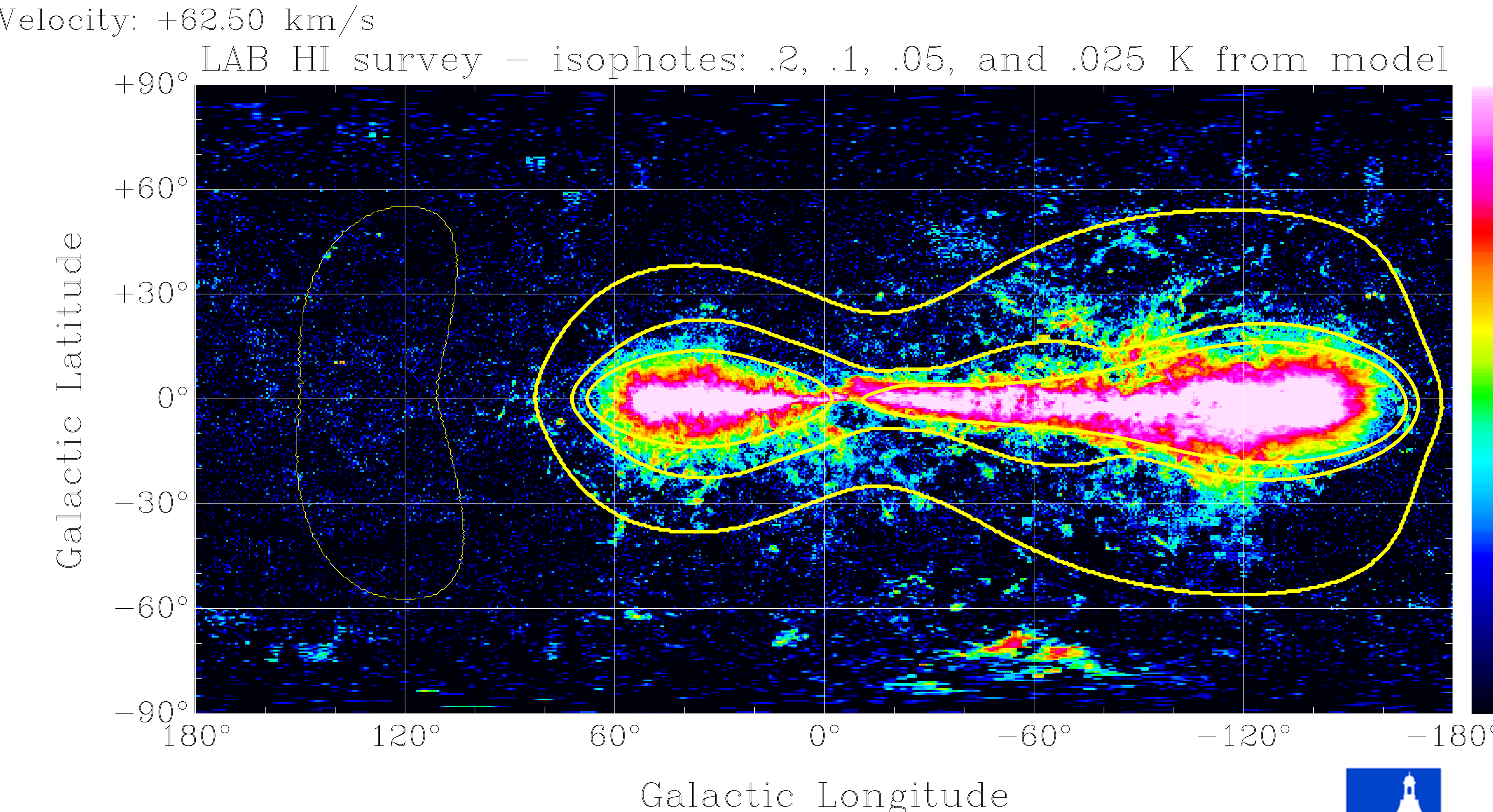
LAB survey corrected for stray radiation



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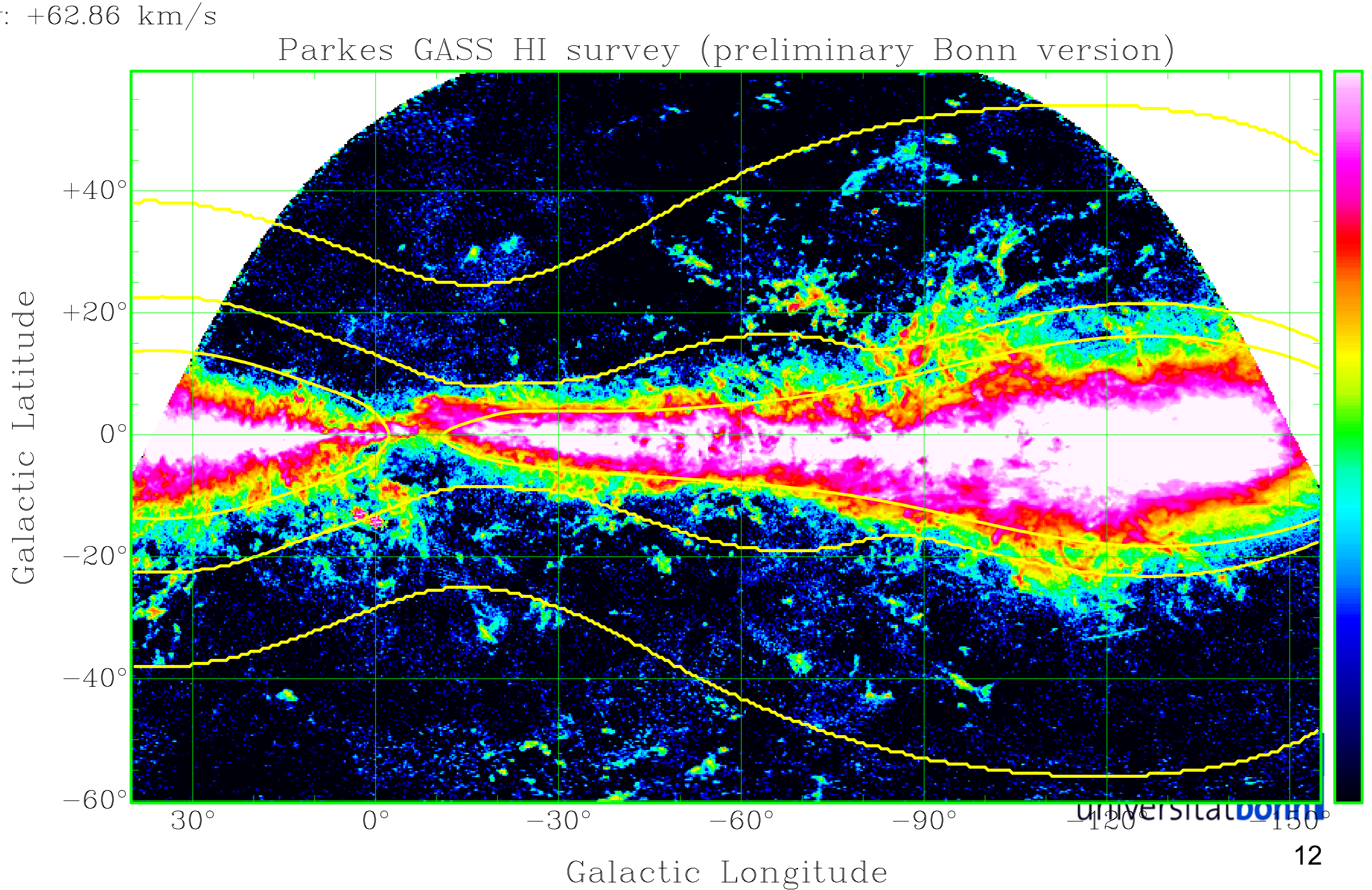
GASS (Parkes) preliminary results



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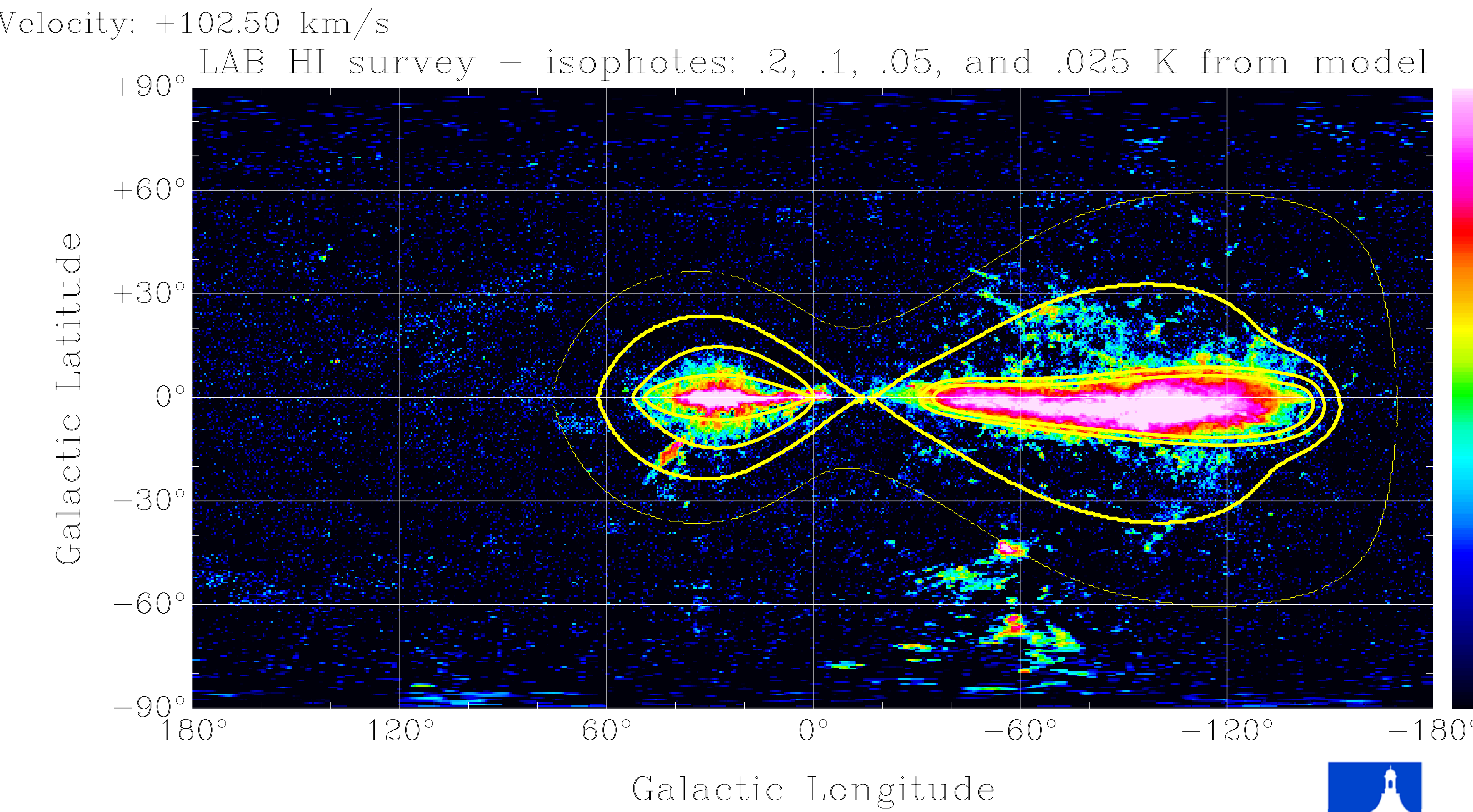
v = 102.5 km/s



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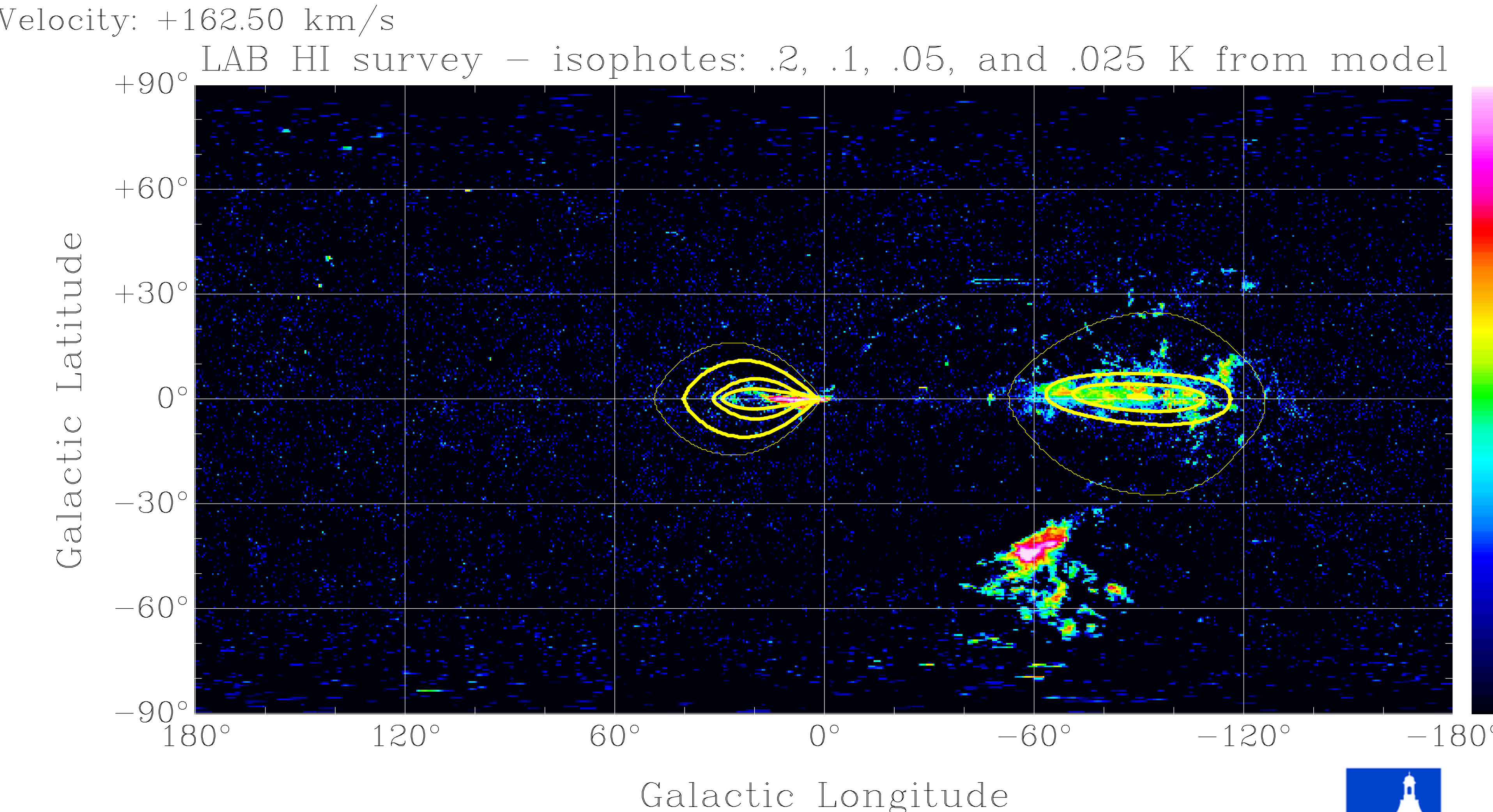
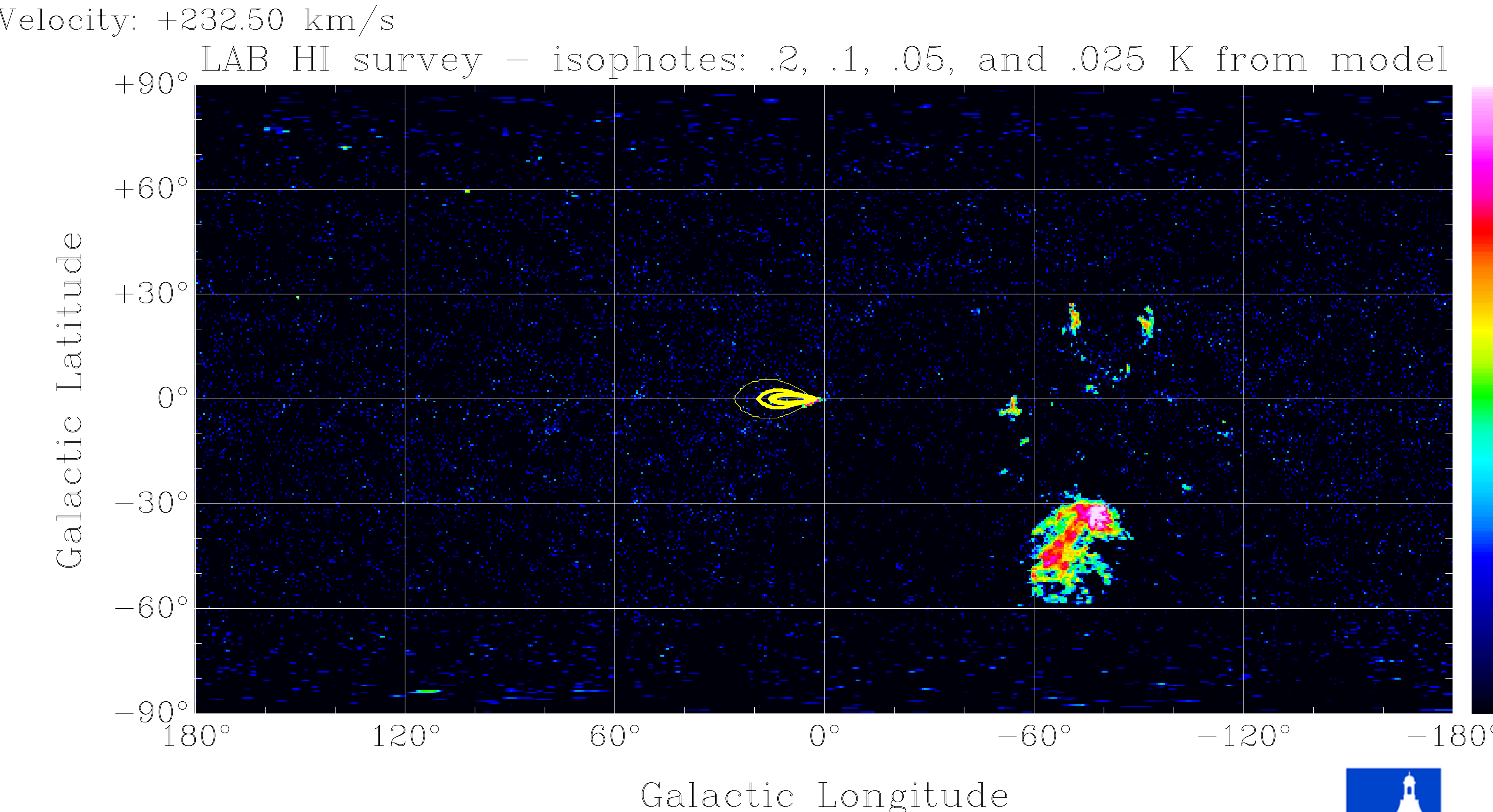
v = 162.5 km/s


Velocity: +162.50 km/s
LAB HI survey – isophotes: .2, .1, .05, and .025 K from model
+90°
+60°
+30°
0°
−30°
−60°
−90°
Galactic Latitude
180°
120°
60°
0°
−60°
−120°
−180°
Galactic Longitude

v = 232.5 km/s



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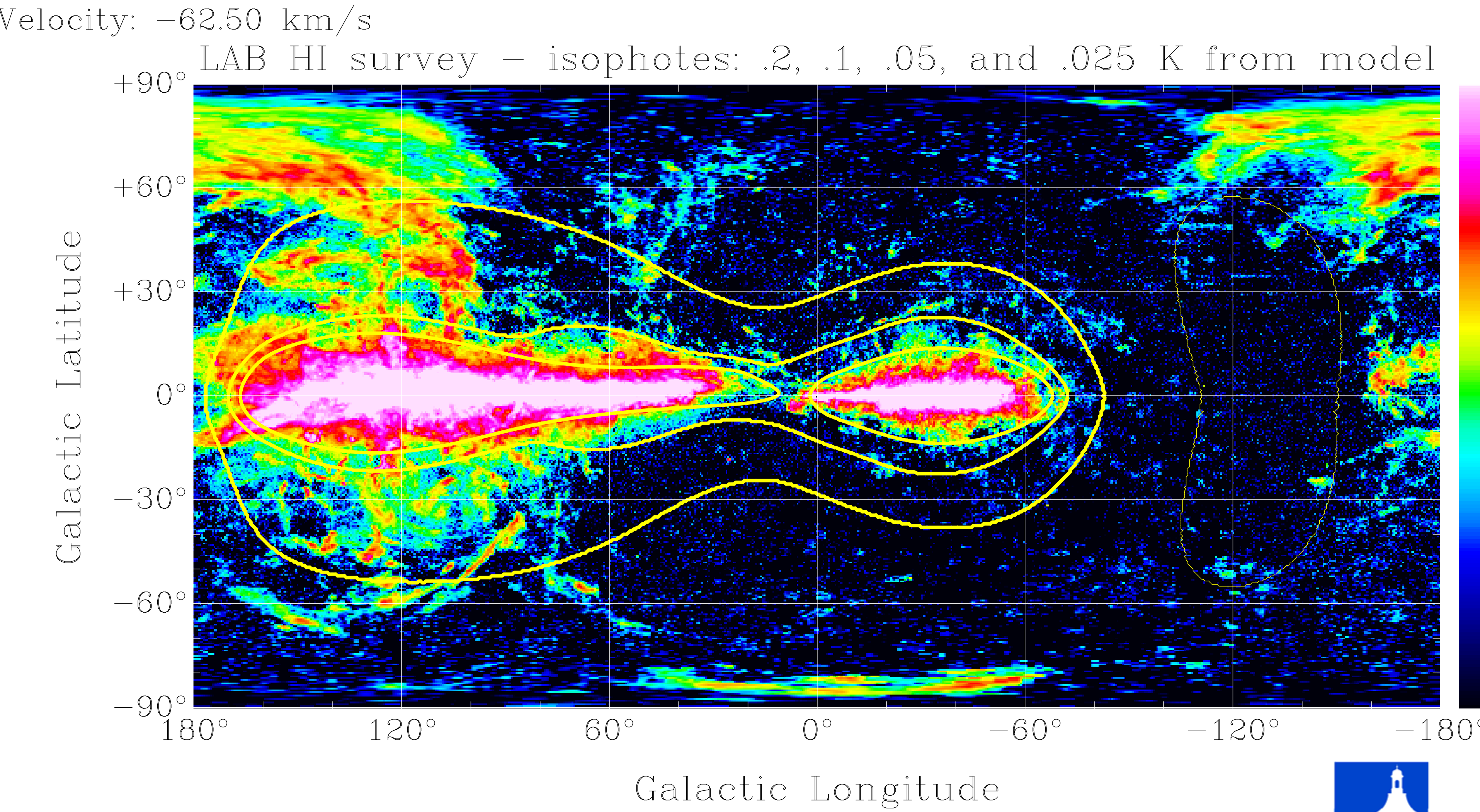
v = -62.5 km/s



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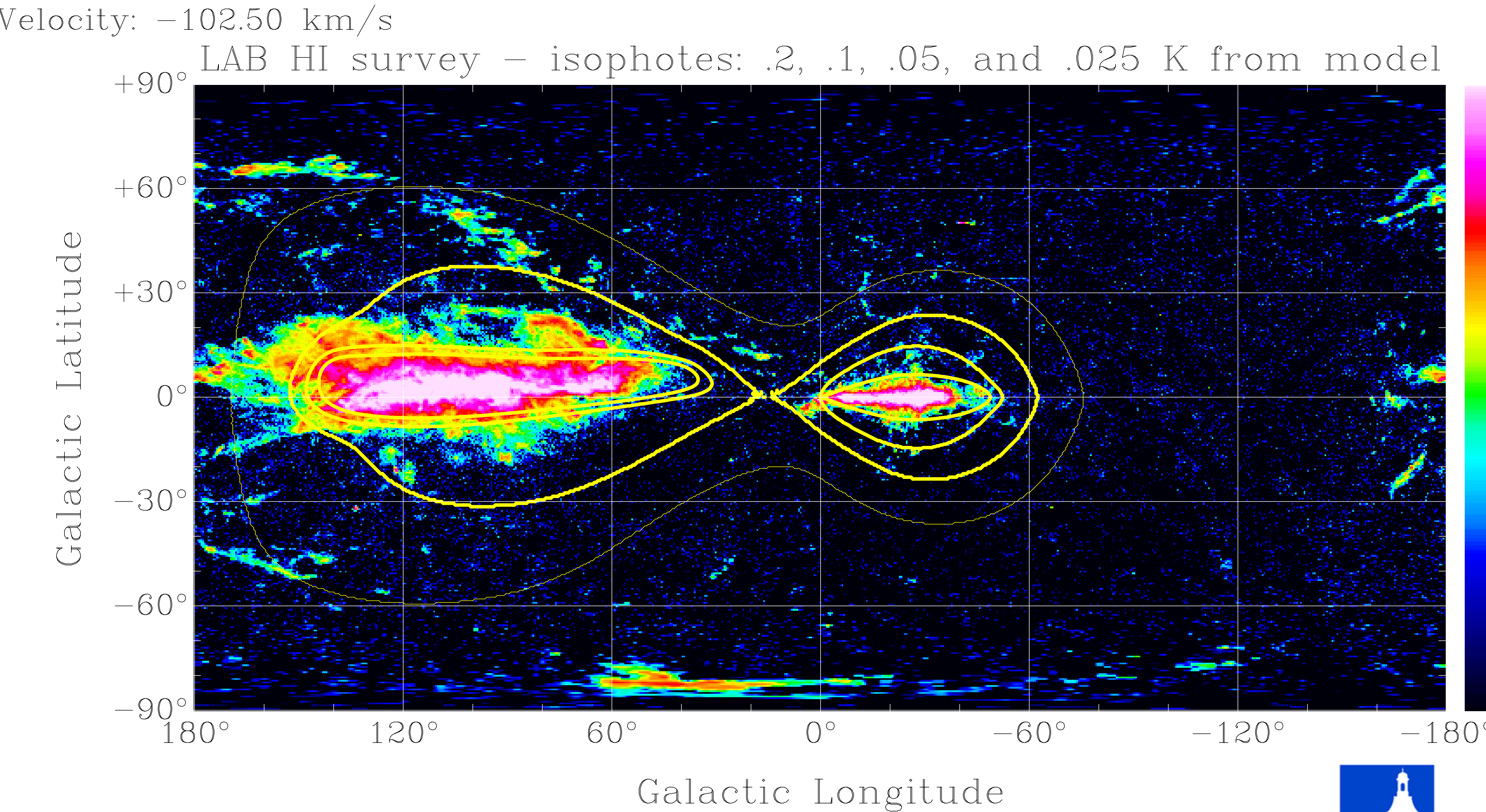
v = -102.5 km/s



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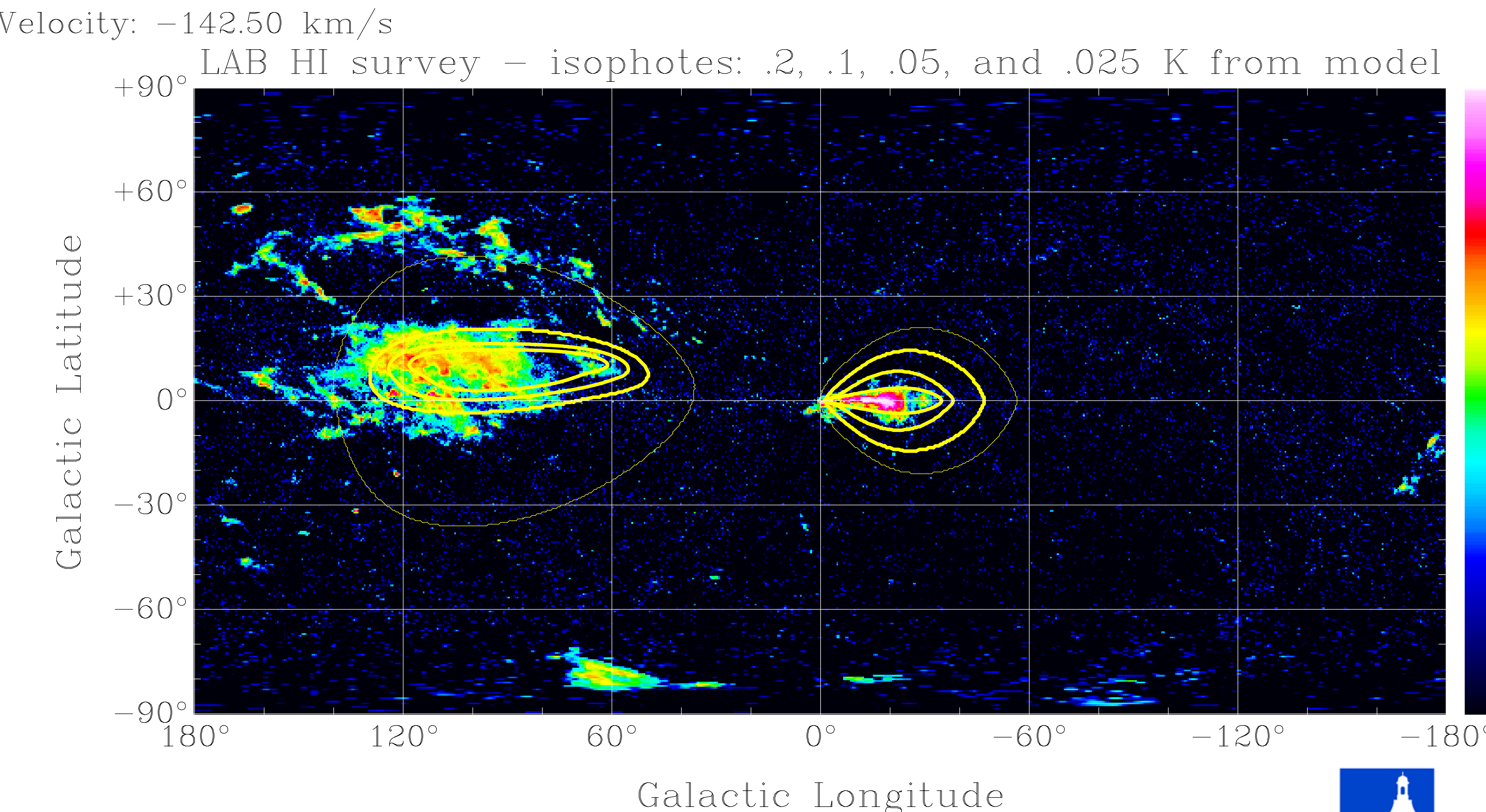
v = -142.5



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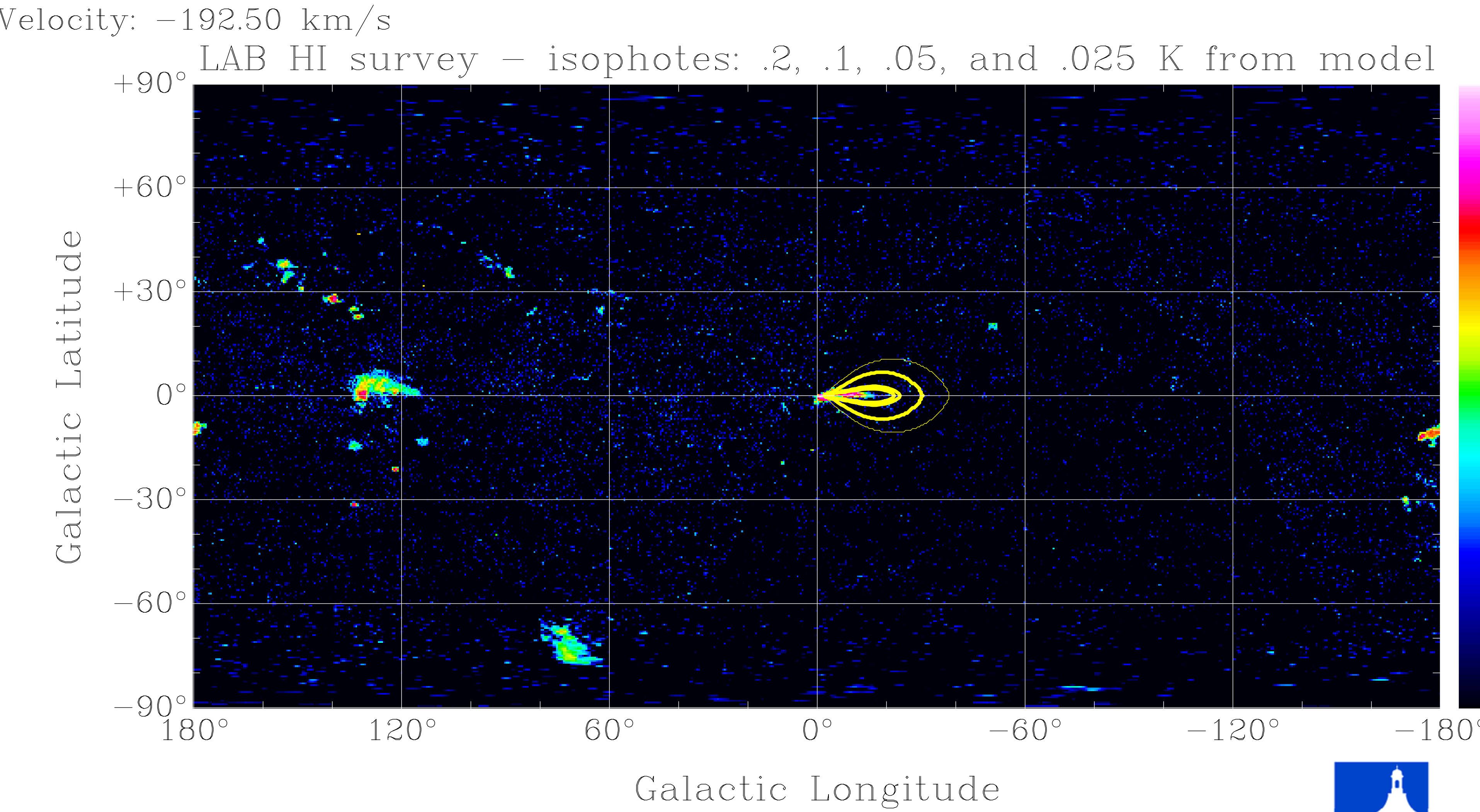
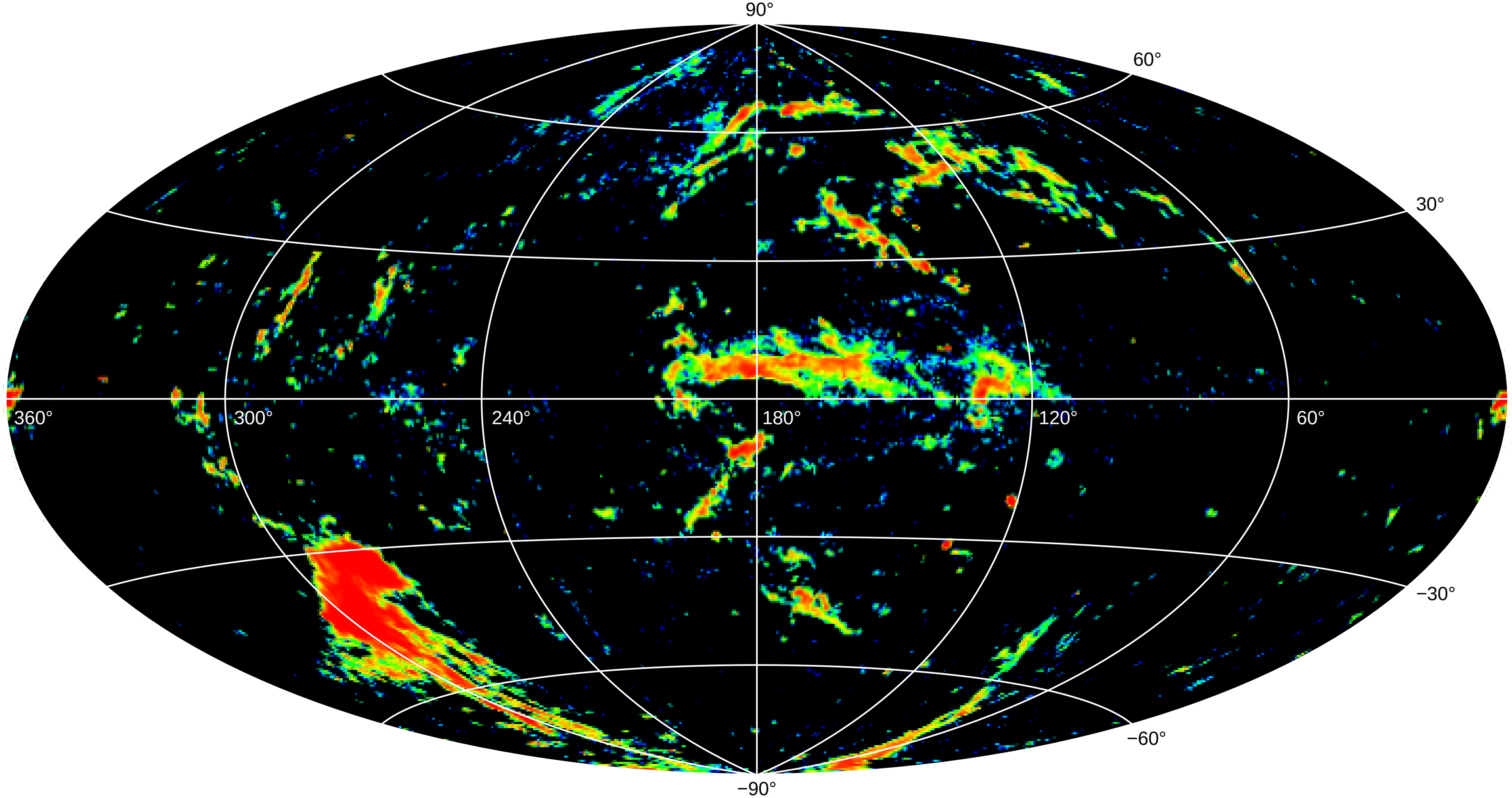
v = -192.5 km/s

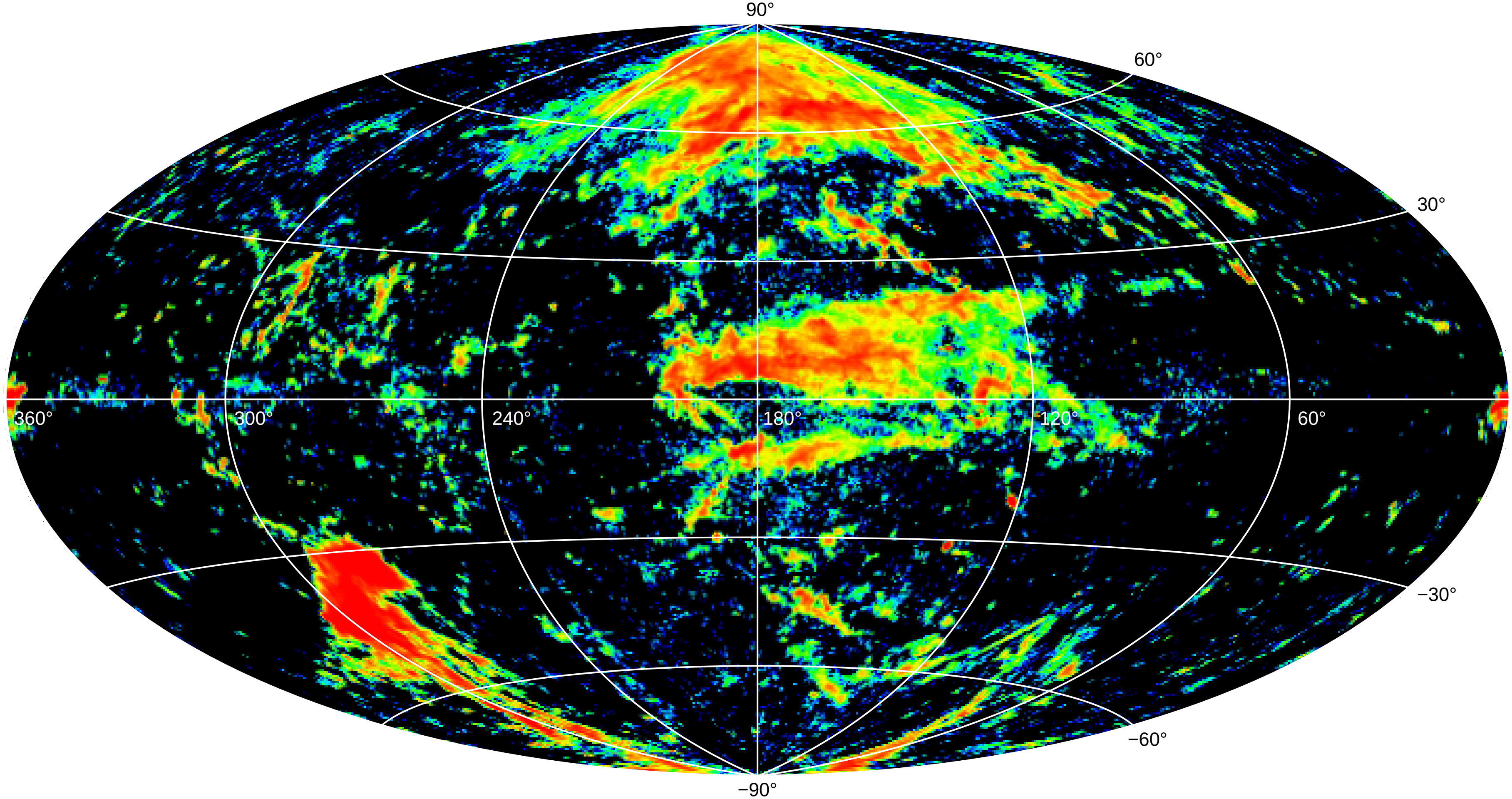


Velocity: −192.50 km/s
LAB HI survey – isophotes: .2, .1, .05, and .025 K from model
+90°
+60°
+30°
0°
−30°
−60°
−90°
Galactic Latitude
180°
120°
60°
0°
−60°
−120°
−180°
Galactic Longitude

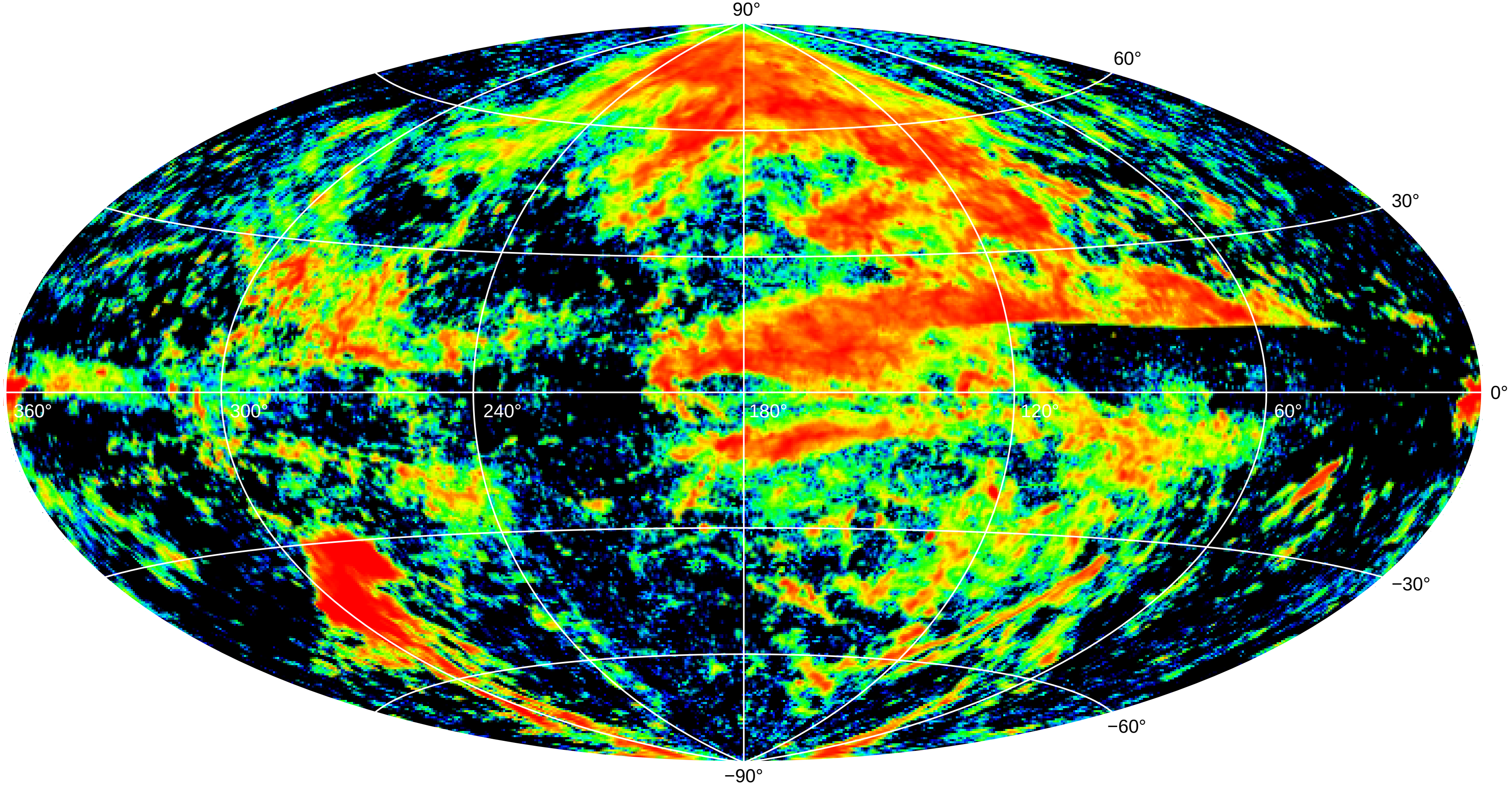
Halo NH column densities, centered at $l=180^0$



Clip data for T > 50 mK



Clip data for T > 100 mK



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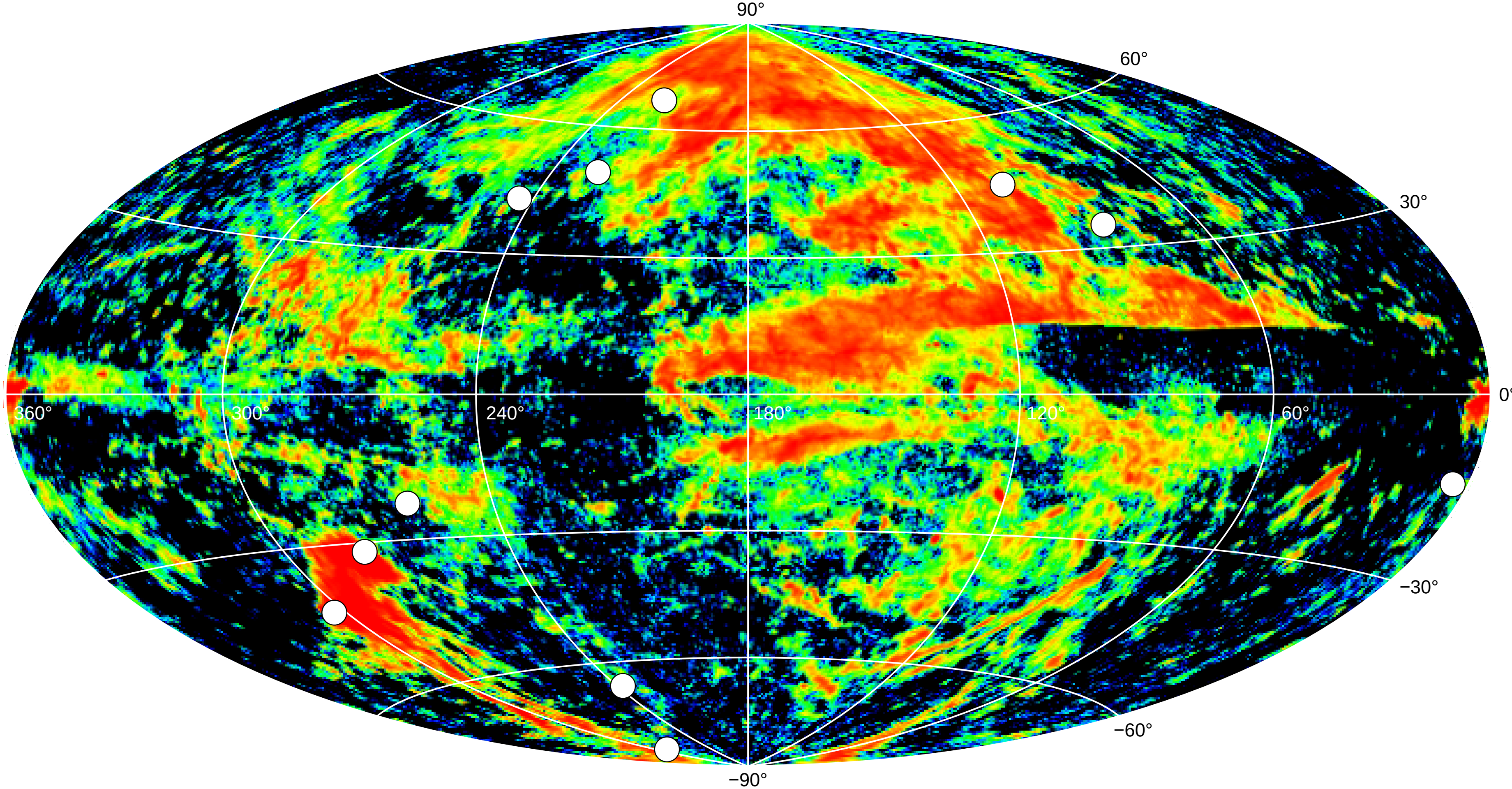
Location of MW “great disk” satellites



Results and conclusions

- Spheroidal or NFW halos are inconsistent with HI flaring
- The Milky Way contains dark matter in a thick disk, twice the mass of the visible baryons (Kalberla et al., 2007)
- The disk contains a dark matter ring at 15 < R < 18 kpc, associated with a stellar ring. The most probable explanation is recent accretion of a dwarf galaxy
- There is evidence for baryons associated with the thick dark matter disk: hot, 10^6 K, and cold, containing HI filaments

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Results and conclusions

- The most distant halo HI gas is the most clumpy
- HI gas closer to the disk is more diffuse
- Extra-planar gas is filamentary (except IVA and outer arm)
- Filaments are oriented preferentially along great circles possibly correlated with “great disk” of MW satellites
- Extra-planar HI gas shows a two-component structure
- The specific turbulent energy density exceeds that of the disk gas by an order of magnitude

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Gravity and gas pressure are in equilibrium

$k_z = \rho^{-1}\, dp/dz$

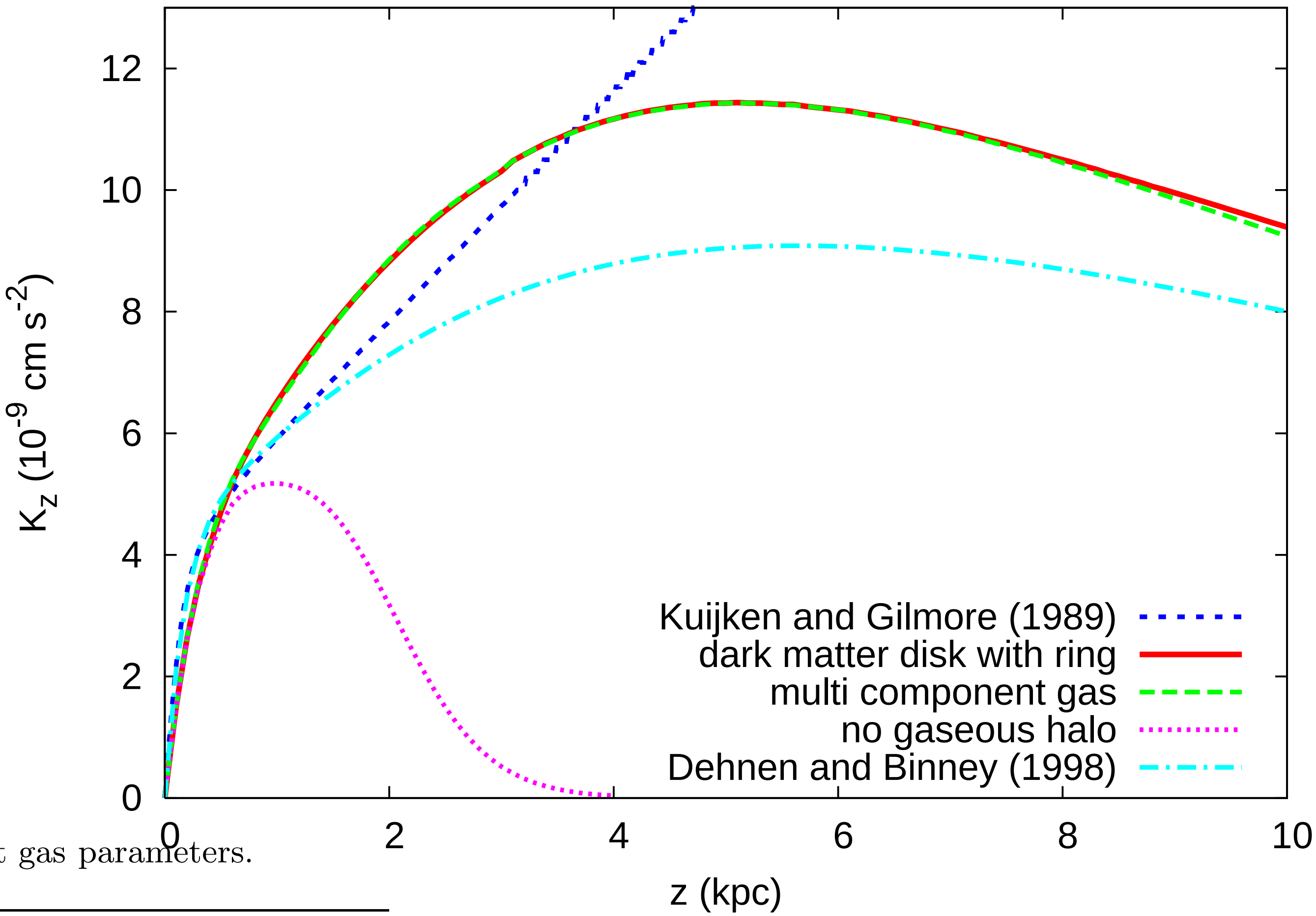

Table 1. Local multi-component gas parameters.

Component	n_{fit} cm^{-3}	n_{obs} cm^{-3}	σ_{fit} $km\ s^{-1}$	σ_{obs} $km\ s^{-1}$
hot halo phase	.0018	.0013	60.0	60.0
neutral halo phase	.0014	.0012	74.0	60.0
DIG	.034	.024	26.8	26.8
WNM	0.19	0.10	14.8	14.8
CNM	0.50	0.30	6.1	6.1

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